AUTOMATIC MODEL REGULATION IN

A DISC DRIVE SERVO SYSTEM USING

MODEL REFERENCE INVERSE

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Related Applications

Ins. A1

This application claims priority of United States provisional application Attorney Docket Number STL10533.01 (Serial Number 60/_____), filed October 23, 2001.

Field of the Invention

This application relates generally to disc drives and more particularly to automatic model regulation in a servo system using model reference inverse.

Background of the Invention

Disc drives are data storage devices that store digital data in magnetic form on a rotating storage medium on a disc. Modern disc drives comprise one or more rigid discs that are coated with a magnetizable medium and mounted on the hub of a spindle motor for rotation at a constant high speed. Information is stored on the discs in a plurality of concentric circular tracks typically by an array of transducers ("heads") mounted to a radial actuator for movement of the heads relative to the discs. Each of the concentric tracks is generally divided into a plurality of separately addressable data sectors. The read/write transducer, e.g. a magnetoresistive read/write head, is used to transfer data between a desired track and an external environment. During a write operation, data is written onto the disc track and during a read operation the head senses the data previously written on the disc track and transfers the information to the external environment. Critical to both of these operations is the accurate locating of the head over the center of the desired track.

A problem in disc drives that limits drive performance in general and head position accuracy specifically is component vibration or resonance. Components in the voice coil motor (VCM) plant of the disc drive exhibit resonance modes that adversely affect the performance of disc drive components. For example, because of resonance in the actuator arm, the transducer heads may not be positioned directly over the desired tracks indicated by the servo control of the

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disc drive. This problem is exacerbated by the recent push to increase the tracks-per-inch (TPI) on the disc surfaces. When TPI is increased, the room for margin in head placement becomes disproportionately smaller, and servo positioning errors become more frequent.

5   Unfortunately, resonance modes in the VCM structure cannot be completely eliminated without extreme cost. The presence of resonance modes in the VCM structure usually causes stability problems in the servo control loop. To overcome these problems, the servo controller is typically augmented with one or more notch filters. The notch filters attenuate the VCM structure response at the natural frequencies of the resonance modes. This combination of the servo controller with the notch filters preserves servo control loop stability but at the expense of

10   closed loop performance.

In a traditional design, a set of fixed notch filters are designed and implemented for a large population of disc drives in a given drive family. In high TPI disc drives, the resonance modes tend to vary both from disc drive to disc drive within the population, and from head to head within each disc drive. Therefore, the fixed notch filters cannot guarantee that the

15   resonance modes will be attenuated for all heads and all drives in the population for which they were designed. This reduces the effectiveness of the notch filters, and results in an increased rejection rate of disc drives.

Ideally, the notch filters will be specifically designed for each head of each individual disc drive. Recently, a method of notch filtering on a per-head basis was disclosed in United States

20   Patent No. 6,246,536, entitled "Notch Filtering as Used in a Disc Drive Servo," issued to Paul Galloway, which is hereby incorporated for all that it teaches and discloses. Unfortunately, even with the Galloway solution, the inherent problems still persist with the use of notch filters. Essentially, notch filters cannot guarantee that the performance criteria will be met in the servo control loop. Two important performance criteria are servo bandwidth and servo runout, or

25   positioning error. When more notch filters are added, for example, phase margin is reduced, which amplifies disturbances in the servo control loop. The amplified disturbances make the servo control loop prone to runout. Thus, while the use of notch filters with a servo controller can provide more stability in the servo control loop, they do so at the cost of performance.

Accordingly, there is a need for a method and apparatus for regulating the response of the

30   VCM plant in a disc drive servo control loop to reduce the effects of unwanted resonance modes,

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guarantee loop stability, and minimize degradation of servo loop performance, without relying on the mechanism of notch filters.

Summary of the Invention

5   Against this backdrop, embodiments of the present invention have been developed. An embodiment of the present invention is a unique method and system for substantially offsetting the effects of unwanted resonance in the VCM plant in a disc drive servo loop. More specifically, an embodiment is an equalization filter that regulates the VCM transfer function such that the response to the output from the servo controller substantially adheres to a

10   predetermined ideal response.

          Embodiments of the invention may be implemented as a computer process, a computing system or as an article of manufacture such as a computer program product or computer readable media. The computer program product may be a computer storage media readable by a computer system and encoding a computer program of instructions for executing a computer process. The

15   computer program product may also be a propagated signal on a carrier readable by a computing system and encoding a computer program of instructions for executing a computer process.

          These and various other features as well as advantages which characterize embodiments of the present invention will be apparent from a reading of the following detailed description and a review of the associated drawings.

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Brief Description of the Drawings

          FIG. 1 is a plan view of a disc drive incorporating a preferred embodiment of the present invention showing the primary internal components.

          FIG. 2 illustrates a functional block diagram of what is commonly referred to as the servo

25   loop of the disc drive.

          FIG. 3 illustrates a portion of the servo loop shown in FIG. 2.

          FIG. 4 is a bode plot showing frequency response of the voice coil motor in a disc drive an embodiment of the present invention.

          FIG. 5 is a high level flow diagram illustrating exemplary steps for regulating the

30   response of the VCM plant of FIG. 2.

FIG. **6** is a detailed flow diagram illustrating exemplary operations that may be employed to realize the equalization filter illustrated in FIGs. **2-3**.

FIG. **7** is a flow diagram illustrating exemplary operations carried out during disc drive operation employing an equalization filter.

Detailed Description

The invention is described in detail below with reference to the drawing figures. When referring to the figures, like structures and elements shown throughout are indicated with like reference numerals.

A disc drive **100** constructed in accordance with a preferred embodiment of the present invention is shown in FIG. **1**. The disc drive **100** includes a base **102** to which various components of the disc drive **100** are mounted. A top cover **104**, shown partially cut away, cooperates with the base **102** to form an internal, sealed environment for the disc drive in a conventional manner. The components include a spindle motor **106**, which rotates one or more discs **108** at a constant high speed. Information is written to and read from tracks on the discs **108** through the use of an actuator assembly **110**, which rotates during a seek operation about a bearing shaft assembly **112** positioned adjacent the discs **108**. The actuator assembly **110** includes a plurality of actuator arms **114** which extend towards the discs **108**, with one or more flexures **116** extending from each of the actuator arms **114**. Mounted at the distal end of each of the flexures **116** is a head **118**, which includes an air bearing slider, enabling the head **118** to fly in close proximity above the corresponding surface of the associated disc **108**.

During a seek operation, the track position of the heads **118** is controlled through the use of a voice coil motor (VCM) **124**, which typically includes a coil **126** attached to the actuator assembly **110**, as well as one or more permanent magnets **128** which establish a magnetic field in which the coil **126** is immersed. The controlled application of current to the coil **126** causes magnetic interaction between the permanent magnets **128** and the coil **126** so that the coil **126** moves in accordance with the well-known Lorentz relationship. As the coil **126** moves, the actuator assembly **110** pivots about the bearing shaft assembly **112**, and the heads **118** are caused to move across the surfaces of the discs **108**.

The spindle motor **106** is typically de-energized when the disc drive **100** is not in use for extended periods of time. The heads **118** are moved over park zones **120** near the inner diameter of the discs **108** when the drive motor is de-energized. The heads **118** are secured over the park zones **120** through the use of an actuator latch arrangement, which prevents inadvertent rotation of the actuator assembly **110** when the heads are parked.

A flex assembly **130** provides the requisite electrical connection paths for the actuator assembly **110** while allowing pivotal movement of the actuator assembly **110** during operation. The flex assembly includes a printed circuit board **132** to which head wires (not shown) are connected; the head wires being routed along the actuator arms **114** and the flexures **116** to the heads **118**. The printed circuit board **132** typically includes circuitry for controlling the write currents applied to the heads **118** during a write operation and a preamplifier for amplifying read signals generated by the heads **118** during a read operation. The flex assembly terminates at a flex bracket **134** for communication through the base deck **102** to a disc drive printed circuit board (not shown) mounted to the bottom side of the disc drive **100**. The disc drive **100** further includes a drive controller **210** (FIG. **2**), which is operable to be coupled to a host system or another controller that controls a plurality of drives. In an illustrative embodiment, the drive controller **210** is a microprocessor, or digital signal processor. The drive controller **210** is either mountable within the disc drive **100**, or is located outside of the disc drive **100** with suitable connection to the actuator assembly **110**.

FIG. **2** illustrates a functional block diagram of what is commonly referred to as the servo loop **200** of the disc drive **100**, employing an embodiment of the present invention. In general, the servo loop **200** includes a disc drive microprocessor **210** having an associated memory **212**, a servo control module **230**, an equalization filter **232**, a trans-conductance amplifier **216**, a VCM plant **234**, and a read/write channel **218**. The VCM plant **234** generally includes the actuator assembly **110**, , the transducer heads **118**, the trans-conductance amplifier **216**, and the VCM **124**. The VCM plant **234** is also referred to as the VCM actuator system. In operation, the microprocessor **210** typically receives a seek command from a host computer (not shown) that indicates that a particular track **120** on the discs **108** is to be accessed. In response to the seek command, the microprocessor **210** determines an appropriate velocity or seek profile to move the head from its current position to the track that is to be accessed. The seek profile is then sent to

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the transconductance amplifier **216** for amplification. The transconductance amplifier **216** then provides a driving current corresponding to the seek profile to the coil **126**. In response to the driving current, the actuator assembly **110** accelerates toward the target track and then decelerates and stops the actuator assembly **110** when the head **118** is over the target track and the seek operation is completed.

The head **118** settles on the target track at the end of the seek operation. Then, a track follow command is received by the microprocessor **210**. During the track follow operation, the servo control **230** functions to hold the head as close to the center of the target track as possible as data is read from and/or written to the target track. The servo control **230** senses servo control data from the target track. Servo control data on the track includes a Position Error Signal (PES) that the servo control **230** uses to monitor how far the head **118** is from the center of the track. In response to a deviation from the center of the track, the servo control **230** sends a control signal to the plant **234** to correct for the deviation. As is discussed in more detail herein, before the plant **234** receives the control signal, the equalization filter **232** filters the control signal to offset, balance, or equalize the effects of unwanted resonance in the plant **234**.

In the embodiment shown in FIG. **2**, and other embodiments described herein, the logical operations of the equalization filter **232** and the servo control module **230** may be implemented as a sequence of computer implemented steps or program modules running on a microprocessor, such as, microprocessor **210**. It will be understood to those skilled in the art that the equalization filter **232** may also be implemented as interconnected machine logic circuits or circuit modules within a computing system. Additionally, the servo control module may be implemented in a separate component of the disc drive **100**, such as a dedicated servo controller. The implementation is a matter of choice dependent on the performance and design requirements of the disc drive **100**. As such, it will be understood that the operations, structural devices, acts, and/or modules described herein may be implemented in software, in firmware, in special purpose digital logic, and/or any combination thereof without deviating from the spirit and scope of the present invention as recited within the claims attached hereto. Furthermore, the various software routines or software modules described herein may be implemented by any means as is known in the art. For example, any number of computer programming languages, such as "C", "C++", Pascal, FORTRAN, assembly language, Java, etc., may be used. Furthermore, various

programming approaches such as procedural, object oriented or artificial intelligence techniques may be employed.

In this embodiment, the computer implemented steps and corresponding digital data that comprise the operations of the equalization filter **232** are stored in some form of computer readable media. As used herein, the term computer-readable media may be any available media that can be accessed by a processor or component that is executing the functions, steps and/or data of the equalization filter **232**. By way of example, and not limitation, computer-readable media might comprise computer storage media and/or communication media.

Computer storage media includes volatile and nonvolatile, removable and non-removable media implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules or other data. Computer storage media includes, but is not limited to, RAM, ROM, EPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to store the desired information and that can be accessed by the computer or processor which is executing the operating code. Computer-readable media may also be referred to as computer program product.

FIG. **3** illustrates an analytical model **300** of a portion of the servo loop **200** employing an equalization filter **232** according to an illustrative embodiment. As can be seen, each of the modules in the portion of the servo loop includes an associated transfer function. The servo control module **230** has a discrete-time domain transfer function K(z). The equalization filter **232** has a discrete-time domain transfer function E(z). The VCM has a continuous-time domain transfer function P(s). The natures of the transfer functions K(z), E(z), and P(s), dictate how each of their associated modules will respond to input signals. During operation, a Position Error Signal (PES) **302** is generated by the demodulator **324**. The PES **302** is negated from a reference signal **304** to obtain an error signal **306**. The error signal **306** is input to the servo control module **230**, which outputs a control signal **308**. The control signal **308** is transmitted to the equalization filter **232**, which filters the control signal **308** using the transfer function E(z). The output of the equalization filter **232** is a digital equalized signal **314**, which is transmitted to a Zero Order Hold (ZOH) module **316**. The ZOH module **316** converts the digitized equalized

signal 314 into an analog equalized signal 317, which is sent to the VCM 318. The VCM 124

may be viewed as having a transfer function P(s) as illustrated by the VCM transfer function 318.

The VCM transfer function 318 exhibits a response to the analog equalized signal 317.

The response from the VCM transfer function 318 is combined with a disturbance signal 320.

5   The disturbance signal 320 represents disturbances to the output of the VCM transfer function

318 due to disc 108 vibration and wind induced VCM actuator vibration. The combination of the

output of the VCM transfer function 318 and the disturbance signal 320 is a head motion signal

321. The head motion signal 321 is generally the position of the transducer head 118 adjacent

the disc surface 108. The head motion signal 321 is sent to the demodulator 324, which uses the

10   head motion signal 321 to sense the position of the head 118 relative to the center of a target

track on the disc 108. The demodulator 324 generates a track identifier identifying the target

track, and a PES 302, indicating how far the head 118 is from the center of the target track. The

PES 302 is fed back into the loop 200 to generate the next error signal 306. During a track

follow operation, the equalization filter 232 compensates for resonance in the VCM plant 234 so

15   that the response as seen by the servo control 230 is substantially ideal. An ideal response is

shown in FIG. 4 in comparison to an equalized response and a non-equalized head response to

illustrate the effect of the equalization filter 232.

The variation of the PES 302 indicates the vibration of the transducer head 118, or the

response of the transducer head 118 to the analog equalized signal 314. The response of the

20   transducer head 118 may be viewed as an aggregation of responses of all the components in the

VCM plant 234, as well as the disturbance signal 320. The servo control module 230 is designed

to handle a particular response of the VCM plant 234, as the response is fed back to the servo

control module 230 in the PES 302.

FIG. 4 is a Bode plot 400 showing three frequency responses of a VCM actuator system,

25   such as the VCM plant 234. For clarity, the phase information has been removed from the Bode

plot 400 and the plot is not shown to scale. The x-axis 410 represents the frequency of the output

signal, while the y-axis 412 represents the VCM system gain in decibels (dB). Shown in the

Bode plot 400 are an ideal frequency response 414, a non-equalized frequency response 416

(darker line), and an equalized frequency response 418. The ideal frequency response 414 is the

30   frequency response of an ideal VCM plant model. The ideal VCM plant model is the model for

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which the servo control module **230** has been designed. Generally, the ideal VCM plant model

includes one or more fundamental resonance modes **415** that are impractical to remove from the

VCM plant. The transfer function for the ideal VCM plant model is discussed in detail below.

The ideal transfer function may be generated analytically and its associated ideal frequency

response **414** may be generated from the analytical model utilizing mathematical software tools

known in the art.

The non-equalized frequency response **416** was experimentally obtained from a disc drive

servo loop that did not employ an equalization filter **232**. The equalized frequency response **418**

was experimentally obtained from a disc drive servo control loop utilizing an embodiment of the

equalization filter **232**. Head 1 was used to generate both the non-equalized frequency response

416 (without an equalization filter **232**) and the equalized frequency response **418** (with an

equalization filter **232**). To generate both the non-equalized frequency response **416** and the

equalized frequency response **418**, a sinusoidal signal is input to the servo control loop at a range

of frequencies.

As is typical, each of the mechanical components of the VCM plant in the disc drive **100**

may have various resonant modes that, if excited by an energy source, will cause the mechanical

components to oscillate at the natural resonance frequencies of the component. Due to the

presence of unwanted resonant modes in the VCM plant of the disc drive **100**, the non-equalized

frequency response **416** does not track the ideal response **414** very closely. As can be seen, the

equalized response of head zero **418** substantially follows the ideal response **414**.

Various methods of implementing an equalization filter **232** may be used with respect to

this embodiment. The equalization filter **232** may be mathematically represented in the general

form:

$$(1) \qquad E_m(z) = \frac{\widetilde{P}(z)}{P_m(z)},$$

where $E_m(z)$ is the transfer function for the equalization filter **232** for the mth head, $P_m(z)$ is the

discrete-time domain transfer function for the mth head of the actual VCM plant **234**, $\widetilde{P}(z)$ is a

discrete-time domain ideal transfer function for an ideal VCM plant, and m is a head number.

Equation (1) represents $E_m(z)$ being determined by computing a relative difference between the

actual VCM plant response, $P_m(z)$, and an ideal VCM plant response, $\tilde{P}(z)$. By implementing the relative difference in the equalization filter **232**, the equalization filter **232** will compensate for unwanted characteristics in the response of the VCM plant **234**. As a result, the feedback response input to the servo control module **230** will be closer to the response for which the servo control **230** was designed. Using equation (1), an equalization filter **232** may be generated for each of m heads in the disc drive **100**.

Occasionally, frequencies of resonance modes will vary for a particular head from one zone to another as the head moves radially over the surface of the disc. A zone, as used in this context means any range of tracks, and does not necessarily refer to the recording zones of the disc. Thus, it is envisioned that more than one equalization filter may be developed and stored for each head of the disc drive. To do so, a transfer function $P_{mi}(z)$ can be determined for each of 'i' zones in which a recording head 'm' may be positioned. An equalization transfer function $E_{mi}(z)$ may then be developed for each of the 'i' zones for each of the 'm' heads.

In one embodiment, the discrete-time domain transfer function $E_m(z)$ is implemented using a state-space implementation. A state-space implementation is described in U.S. Patent No. 6,101,058 issued to John C. Morris, entitled "Method of Implementing a Linear Discrete-Time State-Space Servo Control System on a Fixed-Point Digital Signal Processor in a Disc Drive," which is hereby incorporated for all that it teaches and discloses. Those skilled in the art will readily recognize how to implement the function $E_m(z)$ using the teachings of U.S. Patent No. 6,101,058.

FIG. **5** is a high level flow diagram **500** illustrating exemplary steps for regulating the VCM plant response. Initially, an ideal VCM plant model is selected in a selecting operation **504**. The ideal VCM plant model is preferably an analytical transfer function that exhibits an optimal frequency response. In one implementation, the ideal plant model is universal for all heads in the disc drive plant. In other words, the response characterized by the ideal model is the response that the designer desires the heads to exhibit. Thus, the ideal model depends on the design and criteria to be optimized. Software programs exist in the art that can be used to select and develop the ideal model. The software programs can generate analytical constants that characterize the transfer function for the ideal model. Those constants are stored in memory in the disc drive to be used later in regulating the plant transfer function. The ideal model is

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selected and developed either before manufacture of the disc drive or experimentally during the

manufacture of the disc drive.

After the ideal model has been selected and constants have been stored in memory,

control transfers to a realizing operation **506**, which realizes one or more equalization filters to be

5   implemented in the servo loop **200**. The realizing operation **506** uses the ideal model constants to

generate an equalization filter. In general terms, the realizing operation **506** detects the actual

response of the VCM plant **234** at a number of frequencies, compares the actual response to the

ideal model response at those same frequencies, and generates a transfer function for the

equalization filter. The transfer function generated in the realizing operation **506** may be viewed

10   as including the poles and zeros necessary to counteract the effects of resonance and disturbance

in the VCM plant **234**, such that the overall response to the control signal **308** is a substantially

ideal response.

The ideal plant transfer function $\widetilde{P}$ (z) is given with the general formula:

$$(2) \qquad \widetilde{P}(z) = e^{-z\widetilde{T}} \frac{\widetilde{K}}{z^2} \frac{\widetilde{w}^2}{z^2 + 2\widetilde{\xi}\widetilde{w}\, z + \widetilde{w}^2},$$

where $\widetilde{K}$ and $\widetilde{T}$ are desired DC gain and computational/electronics delay, respectively. The

values $\widetilde{\xi}$ and $\widetilde{w}$ are the desired damping ratio and the desired natural frequency, respectively.

The ideal transfer function shown in equation (2) may be viewed as characterizing that

20   portion of the structural dynamics in the VCM plant of the disc drive **100** that does not vary

significantly from part to part. In other words, it may be viewed as a transfer function for a rigid

body system having one or more fundamental resonance modes, for which the servo control

module **230** is designed. One skilled in the art will readily recognize how an ideal transfer

function can be derived. By way of example, and not limitation, the transfer function in equation

25   (2) may be determined by testing a small population of disc drives that are known to exhibit a

substantially ideal response, and that are substantially static in their response. After gathering a

desired number of data points that characterize the response of the substantially ideal transfer

function, the data points may be fitted to a curve. Computer software known in the art may then

be run on a computer to derive the analytical expression for $\widetilde{P}(z)$ shown in equation (2).

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Referring again to FIG. 5, parameters that define the ideal model determined in the selecting operation **504** are input to the realizing operation **506**. In one embodiment of the realizing operation **506**, a measuring operation **604** measures the actual response of the VCM plant **234**. Preferably the measuring operation **604** is performed by inputting a sinusoid signal at a number of frequencies and detecting the frequency response of the VCM plant **234**. The frequency response data that is measured is preferably point wise numerical data that may be used to compare to ideal model response data to generate an equalization filter transfer function. For example, sinusoid signals at varying frequencies may be input servo control loop and the response detected. The sinusoid signals may range in frequency from 100 Hz to half of the disc drive sampling frequency, located at 10 Hz increments. The frequency response of the VCM plant **234** may be measured at each 10Hz increment. Thus, a plurality of point data is generated in the measuring operation **604**. The plurality of point data is preferably stored in memory for the next step.

The next step is a calculating operation **608**, which calculates an equalization filter. The equalization filter is an infinite impulse response (IIR) filter that compensates for the deviations between the response of an ideal model and the actual VCM plant **234**. An equalization filter is calculated for each head in the disc drive and stored in memory for use during operation. The method steps illustrated in the flow diagram **500** may be executed at manufacturing time, and subsequently re-executed within the disc drive at other selected times. For example, the equalization filter transfer function could be recomputed during selected recovery modes. Additionally, where practical, the equalization filter could be recomputed during every power up sequence.

FIG. 6 is a flow diagram **700** illustrating exemplary steps that may be employed in the disc drive **100** to generate one or more equalization filters **232**. A selecting operation selects a transducer head **118** in the disc drive for which an associated equalization filter **232** will be generated. An inputting operation **704** inputs actual response values obtained from the VCM plant **234** corresponding to the selected head **118**. The actual response values that are input may be values that are output from the VCM transfer function **318** shown in FIG. 3. The values may be viewed as all of the values on the non-equalized response curve **416** shown in FIG. 4. The actual response values are obtained by inputting to the servo control loop **200** a set of sinusoidal

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signals having predetermined frequencies within a frequency range. For every actual response value, there is an associated ideal response value at an associated frequency, as illustrated in the plots in FIG. 4.

5   Thus, after the actual response values are input, control transfers to a second input operation **708** wherein ideal model frequency response values are input.   The ideal model values are preferably read out of memory where they was previously stored during manufacture based on the desired ideal response (e.g., the ideal response **414**). The ideal response values are the same for every head **118** in the disc drive **100**. The ideal response and its associated transfer function are described with respect to equation (2). After the actual response value and the ideal

10   model value are input, control transfers to a dividing operation **712** wherein the ideal model values are divided by the actual response values. The quotients derived in the dividing operation **712** are preferably stored in memory to be used later.

In one embodiment, the inputting operations **704** and **708**, and the dividing operation **712**, are performed in an iterative fashion. First, an actual response value is input in the inputting

15   operation **704**. Then an ideal model value is input in the inputting operation **708**. The ideal value is then divided by the actual value in the dividing operation **712**. The quotient from the dividing operation **712** is stored. In this particular embodiment, the operations **704**, **708**, and **712** are repeated for every set of ideal and actual values. The plurality of stored quotients are then used to derive a frequency response of the equalization filter **232**. One way of deriving the

20   frequency response of the equalization filter **232** is to fit the quotients to a curve.

Control transfers to a fitting operation **718** wherein all of the stored quotients from the dividing operation **712** are fitted to a curve. Software algorithms are available and readily apparent to those skilled in the art for fitting a curve in the fitting operation **718**. The fitting operation **718** involves deriving an analytical function for the fitted curve. After the analytical

25   function is derived, control transfers to a storing operation **722**, wherein the derived analytical transfer function is stored in memory. The analytical transfer function that is stored typically involves storing a number of coefficients that characterize the transfer function. The stored transfer function represents the equalization filter **232** discussed earlier. Control then transfers to a determining operation **726** wherein it is determined whether all of the heads have been analyzed

30   for their response. If it is determined that one or more heads remain to be analyzed, control

transfers to a switching operation **730** wherein the disc drive **100** switches to the next head. After the switching operation **730**, control transfers back to the inputting operation wherein an actual response values for the next head are input for processing. If all the heads have been analyzed in the determining operation **726**, processing ends.

5   Fig. **7** is a flow diagram **800** illustrating exemplary method steps employed during the operation of the disc drive **100** to position a transducer head **118** and utilizing an equalization filter **232**. Control initially transfers to a determining **804** wherein a target location on the disc **108** is determined. The target location is typically based on a read or write command to access the disc **108**, and is associated with a logical block address. After the target location is determined, control transfer transfers to a determining operation **808** wherein it is determined which of the transducer heads **118** will be used to access the target location. Control then transfers to a selecting operation **812** identifying and retrieving an equalization filter associated with the determined head in operation **808** is selected. For each head in the disc drive **100**, there is an equalization filter **232** adapted for resonance modes by the head **118**. Thus, in the selecting operation **812**, a particular equalization filter **232** is selected that corresponds to the head that will be used to access the target location on a target track (e.g., track **120**).

In response to the seek command **819** to the VCM, the read/write head is positioned close to the target track. Following the completion of the seek command, the actuator is in a track-follow mode, wherein a primary objective is to maintain the position of the read/write head over the target track with minimum error. In the track-follow mode, control then transfers to a generating operation **818** wherein a control signal is generated to the VCM plant **234** to adjust the position of the head closely to the target location. Control then transfers to a filtering operation **822** wherein the control signal is filtered using the equalization filter selected in the selecting operation **812**. In the filtering operation **822**, a filtered control signal is transmitted to the VCM, to energize the VCM for maintaining the position of the transducer head **118** over the target track. Advantageously, the resonance modes associated with the head that is used to access the target track, are attenuated by the selected equalization filter that is designed to counteract those particular resonance modes. The method steps illustrated in Fig. **7** are typically iterated every time the disc is to be accessed in response to a disc access command.

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The method steps illustrated in FIGs. 5-7 may be implemented in firm ware in the disc drive or in a computer connected to a disc drive. Additionally, the logical operations of the various embodiments of the present invention are implemented (1) as a sequence of computer implemented acts or program modules running on a computing system and/or (2) as

5   interconnected machine logic circuits or circuit modules within the computing system. The implementation is a matter of choice dependent on the performance requirements of the computing system implementing the invention. Accordingly, the logical operations making up the embodiments of the present invention described herein are referred to variously as operations, structural devices, acts or modules. It will be recognized by one skilled in the art that these

10   operations, structural devices, acts and modules may be implemented in software, in firmware, in special purpose digital logic, and any combination thereof without deviating from the spirit and scope of the present invention as recited within the claims attached hereto.

To summarize, an embodiment of the present invention may be viewed as a method of regulating a response of a voice coil motor plant (such as **234**) in a disc drive (such as **100**) by

15   selecting an ideal response (such as **414**), measuring an actual response (such as **416**) of the voice coil motor plant (such as **234**) at predetermined frequencies, and realizing (such as **506**) an equalization filter (such as **232**) for offsetting the unwanted resonance modes based on the ideal response (such as **414**) and the actual response (such as **414**). The method may further include dividing (such as **712**) ideal response values (such as **414**) by corresponding actual response

20   values (such as **416**) to yield equalized response values (such as **418**) characteristic of an equalized response.

Another embodiment is a disc drive (such as **100**) having a servo control module (such as **230**) and a voice coil motor (VCM) plant (such as **234**). The disc drive (such as **100**) has memory (such as **212**) storing predetermined ideal VCM plant response parameters representing

25   an ideal VCM plant response (such as **414**) for which the servo control module (such as **230**) is designed to interact. The disc drive (such as **100**) further includes a measuring module (such as **210**) operable to measure an actual VCM plant response (such as **416**) and a realizing module (such as **210**) operable to generate an equalization filter (such as **232**) for filtering resonance modes that are in the actual VCM plant response (such as **416**) but not in the ideal VCM plant

30   response (such as **414**).

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Yet another embodiment may be viewed as a method employed in a disc drive (such as **100**) for controlling the transducer head (such as **118**) by inputting (such as **704**) actual voice coil motor plant response values, which represent a frequency response (such as **416**) of an actual VCM plant (such as **234**) to one or more sinusoidal signal(s) at predetermined frequencies. The

5 method further involves inputting (such as **708**) ideal VCM plant model values that represent an ideal VCM plant model frequency response (such as **415**) at the predetermined frequencies. The method further involves determining (such as **608**) relative differences between the ideal VCM plant model values and the actual VCM plant values at each of the predetermined frequencies, and realizing (such as **506, 718, and 722**) an equalization filter (such as **232**) that when working

10 in combination with the actual VCM plant (such as **234**), the combination yields a response (such as **418**) that is substantially equal to the ideal VCM plant model response (such as **415**). In one embodiment, determining (such as **608**) the relative differences between ideal (such as **415**) and actual (such as **416**) responses may involve dividing (such as **712**) each of the ideal VCM plant model values with an associated actual VCM plant value to yield a plurality of equalization

15 values. In an embodiment, realizing (such as **506**) the equalization filter (such as **232**) involves fitting (such as **718**) the equalization values to a curve, deriving an analytical function that defines the curve, and storing (such as **722**) parameters associated with the analytical function to be used during operation as the equalization filter (such as **232**).

It will be clear that the present invention is well adapted to attain the ends and advantages

20 mentioned as well as those inherent therein. While a presently preferred embodiment has been described for purposes of this disclosure, various changes and modifications may be made which are well within the scope of the present invention. For example, the equalization filter could be employed in other (non-disc drive) environments where mechanical resonance modes arise and reduce performance of servo control. Additionally, analog versions of the equalization filter may

25 be suitable for analog environments and may be readily apparent to those skilled in the art. Numerous other changes may be made which will readily suggest themselves to those skilled in the art and which are encompassed in the spirit of the invention disclosed and as defined in the appended claims.